

### Solution 1: AdaBoost - Updates

- (a) For the first case, only one sample is incorrect. The weighted in-sample misclassification rate can be calculated as:

$$\text{err}^{[m]} = \sum_{i=1}^n w^{[m](i)} \cdot \mathbb{1}_{\{y^{(i)} \neq \hat{b}^{[m]}(\mathbf{x}^{(i)})\}} = 0.01 \quad (1)$$

We can now calculate the weight of the base learner:

$$\hat{\beta}^{[m]} = \frac{1}{2} \log \left( \frac{1 - \text{err}^{[m]}}{\text{err}^{[m]}} \right) = 0.5 \cdot \log \left( \frac{0.99}{0.01} \right) = \log(\sqrt{99}) \quad (2)$$

The updated weights are then calculated as:

$$\begin{aligned} w^{[m+1](i)} &= w^{[m](i)} \cdot \exp \left( -\hat{\beta}^{[m]} \cdot \underbrace{y^{(i)} \cdot \hat{h}(\mathbf{x}^{(i)})}_{\{-1,1\}} \right) \\ &= \begin{cases} 0.01 \cdot \exp(-\log(\sqrt{99}) \cdot 1 \cdot 1) & \text{if } i = 1, \dots, 4, 6, \dots, 10 \\ 0.01 \cdot \exp(-\log(\sqrt{99}) \cdot 1 \cdot -1) & \text{if } i = 5 \\ 0.1 \cdot \exp(-\log(\sqrt{99}) \cdot 1 \cdot 1) & \text{if } i = 11, \dots, 19 \end{cases} \\ &= \begin{cases} 0.001 & \text{if } i = 1, \dots, 4, 6, \dots, 10 \\ 0.0995 & \text{if } i = 5 \\ 0.01 & \text{if } i = 11, \dots, 19 \end{cases} \end{aligned} \quad (3)$$

- (b) In the second case, five out of the 9 samples with weight 0.1 are misclassified. The weighted in-sample misclassification rate can be calculated as:

$$\text{err}^{[m]} = \sum_{i=1}^n w^{[m](i)} \cdot \mathbb{1}_{\{y^{(i)} \neq \hat{b}^{[m]}(\mathbf{x}^{(i)})\}} = 0.5 \quad (4)$$

We can now calculate the weight of the base learner:

$$\hat{\beta}^{[m]} = \frac{1}{2} \log \left( \frac{1 - \text{err}^{[m]}}{\text{err}^{[m]}} \right) = 0.5 \cdot \log \left( \frac{0.5}{0.5} \right) = 0 \quad (5)$$

The updated weights are then calculated as:

$$\begin{aligned} w^{[m+1](i)} &= w^{[m](i)} \cdot \exp \left( -\hat{\beta}^{[m]} \cdot \underbrace{y^{(i)} \cdot \hat{h}(\mathbf{x}^{(i)})}_{\{-1,1\}} \right) \\ &= \begin{cases} 0.01 \cdot \exp(-0 \cdot 1 \cdot 1) & \text{if } i = 1, \dots, 10 \\ 0.1 \cdot \exp(-0 \cdot 1 \cdot -1) & \text{if } i = 15, 16, 17, 18 \\ 0.1 \cdot \exp(-0 \cdot 1 \cdot 1) & \text{if } i = 11, \dots, 14, 19 \end{cases} \\ &= \begin{cases} 0.01 & \text{if } i = 1, \dots, 4, 6, \dots, 10 \\ 0.1 & \text{if } i = 5 \\ 0.1 & \text{if } i = 11, \dots, 19 \end{cases} \end{aligned} \quad (6)$$

When the weighted in-sample misclassification rate is 0.5, the weight of the base learner is 0 and we don't do any updates to the weights.

- (c) In the third case, all samples with the exception of one with a weight of 0.01 are misclassified. The weighted in-sample misclassification rate can be calculated as:

$$\text{err}^{[m]} = \sum_{i=1}^n w^{[m](i)} \cdot \mathbb{1}_{\{y^{(i)} \neq \hat{b}^{[m]}(\mathbf{x}^{(i)})\}} = 0.99 \quad (7)$$

We can now calculate the weight of the base learner:

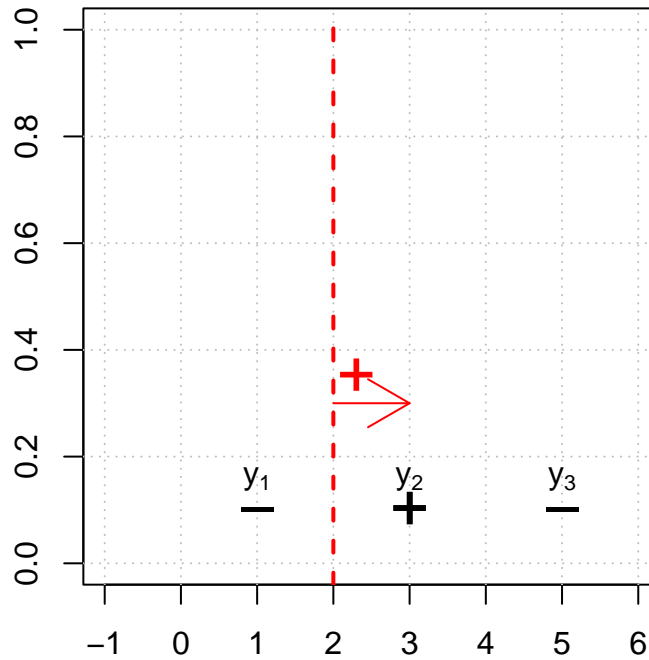
$$\hat{\beta}^{[m]} = \frac{1}{2} \log \left( \frac{1 - \text{err}^{[m]}}{\text{err}^{[m]}} \right) = 0.5 \cdot \log \left( \frac{0.01}{0.99} \right) = \log \left( \sqrt{\frac{1}{99}} \right) \quad (8)$$

The updated weights are then calculated as:

$$\begin{aligned} w^{[m+1](i)} &= w^{[m](i)} \cdot \exp \left( -\hat{\beta}^{[m]} \cdot \underbrace{y^{(i)} \cdot \hat{h}(\mathbf{x}^{(i)})}_{\{-1,1\}} \right) \\ &= \begin{cases} 0.01 \cdot \exp \left( -\log \left( \sqrt{\frac{1}{99}} \right) \cdot 1 \cdot -1 \right) & \text{if } i = 1, \dots, 9 \\ 0.01 \cdot \exp \left( -\log \left( \sqrt{\frac{1}{99}} \right) \cdot 1 \cdot 1 \right) & \text{if } i = 10 \\ 0.1 \cdot \exp \left( -\log \left( \sqrt{\frac{1}{99}} \right) \cdot 1 \cdot -1 \right) & \text{if } i = 11, \dots, 19 \end{cases} \\ &= \begin{cases} 0.001 & \text{if } i = 1, \dots, 9 \\ 0.0995 & \text{if } i = 10 \\ 0.01 & \text{if } i = 11, \dots, 19 \end{cases} \end{aligned} \quad (9)$$

## Solution 2: AdaBoost - Decision Stump

- (a) The initial weights all three points in the dataset is  $\frac{1}{3}$ . A decision boundary for the first decision stump could be the line  $x = 2$ .



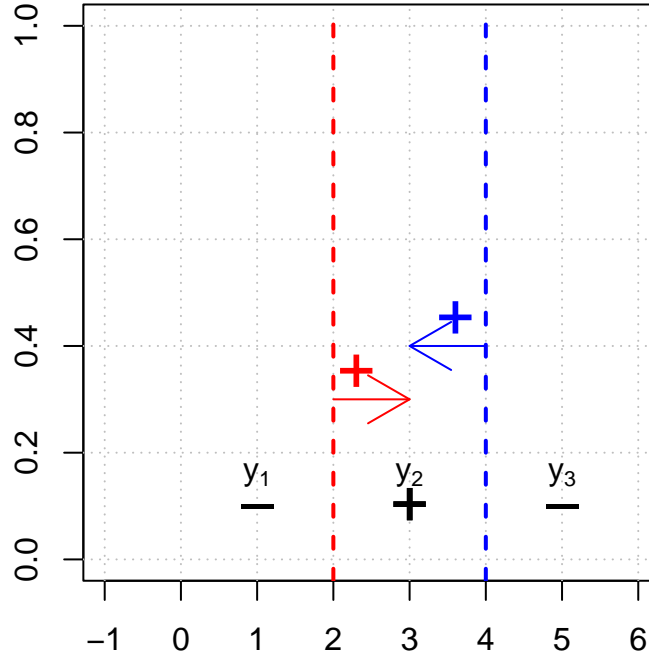
- (b) The first stump makes two correct predictions and one incorrect prediction, we can then calculate the weighted in-sample misclassification rate, the weight for the stump and the new data points weights

$$\begin{aligned}
\text{err}^{[0]} &= \sum_{i=1}^n w^{[0](i)} \cdot \mathbb{1}_{\{y^{(i)} \neq \hat{b}^{[0]}(\mathbf{x}^{(i)})\}} = 0.33 \\
\hat{\beta}^{[0]} &= \frac{1}{2} \log \left( \frac{1 - \text{err}^{[0]}}{\text{err}^{[0]}} \right) = 0.5 \cdot \log \left( \frac{0.66}{0.33} \right) \approx 0.35 \\
w^{[1](1)} &= w^{[0](1)} \cdot \exp \left( -\hat{\beta}^{[0]} \cdot y^{(1)} \cdot \hat{b}^{[0]}(\mathbf{x}^{(1)}) \right) = 0.33 \cdot \exp(-0.35 \cdot -1 \cdot -1) \approx 0.23 \\
w^{[1](2)} &= w^{[0](2)} \cdot \exp \left( -\hat{\beta}^{[0]} \cdot y^{(2)} \cdot \hat{b}^{[0]}(\mathbf{x}^{(2)}) \right) = 0.33 \cdot \exp(-0.35 \cdot 1 \cdot 1) \approx 0.23 \\
w^{[1](3)} &= w^{[0](3)} \cdot \exp \left( -\hat{\beta}^{[0]} \cdot y^{(3)} \cdot \hat{b}^{[0]}(\mathbf{x}^{(3)}) \right) = 0.33 \cdot \exp(-0.35 \cdot 1 \cdot -1) \approx 0.47
\end{aligned} \tag{10}$$

We need to normalize the weights so that they sum up to one:

$$\begin{aligned}
w^{[1](1)} &= \frac{w^{[1](1)}}{\sum_{i=1}^n w^{[1](i)}} = \frac{0.23}{0.23 + 0.23 + 0.47} \approx 0.25 \\
w^{[1](2)} &= \frac{w^{[1](2)}}{\sum_{i=1}^n w^{[1](i)}} = \frac{0.23}{0.23 + 0.23 + 0.47} \approx 0.25 \\
w^{[1](3)} &= \frac{w^{[1](3)}}{\sum_{i=1}^n w^{[1](i)}} = \frac{0.47}{0.23 + 0.23 + 0.47} \approx 0.50
\end{aligned} \tag{11}$$

- (c) As the training error is not yet 0, we do a second stump using the new weights, The decision boundary is  $x=4$ . The stump makes two correct predictions and one incorrect prediction:



We calculate the weighted in-sample misclassification rate and the weight for the stump.

$$\begin{aligned} \text{err}^{[1]} &= \sum_{i=1}^n w^{[1](i)} \cdot \mathbb{1}_{\{y^{(1)} \neq \hat{b}^{[1]}(\mathbf{x}^{(i)})\}} = 0.25 \\ \hat{\beta}^{[1]} &= \frac{1}{2} \log \left( \frac{1 - \text{err}^{[1]}}{\text{err}^{[1]}} \right) = 0.5 \cdot \log \left( \frac{0.75}{0.25} \right) \approx 0.54 \end{aligned} \tag{12}$$

We can see that for the left-most point and the right-most point, there is a disagreement between our two stumps. In the case of the right-most point, the second stump has a bigger weight than the first one, so we will classify it correctly as  $y = -1$ . Unfortunately, in the case of the left-most point, we will classify it incorrectly as  $y = 1$ . We will need a third iteration that will correct this mistake.

